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EFFECTS OF SEARCH AREA SIZE ON TARGET ACQUISITION WITH PASSIVE NIGHT VISION DEVICES

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BESRL

U. S. Army

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FOREWORD

The NIGHT OPERATIONS Program within the Behavior and Systems Research Laboratory (BESRL) is concerned with optimizing human performance in relation to night vision devices and related sensors. Specific aspects deal with determining: performance effectiveness of sensor systems; factors which affect performance; and means of improving effectiveness. The entire research program is responsive to requirements of the Combat Developments Command and is conducted under RDT&E Project 2Q024701A723, Human Performance in Military Systems, FY 1971 Work Program.

To further the research, a BESRL field unit at Fort Ord, California, with the support of the Combat Developments Command Experimentation Command (CDCEC), is currently conducting experimentation with passive night vision devices. Personnel of the Behavior and Systems Research Laboratory are deeply appreciative of the excellent support given the research program by CDCEC, both in personnel and materiel. Special acknowledgment is made of the efforts of the Commander, Brigadier General T. W. Brown, and of Project Team III which, under the command of Lieutenant Colonel J. Fulton, directly supported the research activity.

The level of effectiveness of the passive night vision devices is highly dependent upon how they are used. The present publication reports on research to determine the implications of search area size for operational use, basis of issue, search deployment, and for improvement of soldier effectiveness with these devices.

BESRL research in night operations is conducted as an in-house research effort augmented by research contracts with organizations selected as having unique capabilities for research in this area. The present study was conducted under program direction of Mr. Jack J. Sternberg, Behavior and Systems Research Laboratory, with the assistance of personnel of Manned Systems Sciences, Inc., Northridge, California.

J. E. UHLANER, Director
Behavior and Systems
Research Laboratory

EFFECT OF SEARCH AREA SIZE ON TARGET ACQUISITION WITH PASSIVE NIGHT VISION DEVICES

BRIEF

Requirement:

To determine the effect of search area size on performance with passive night vision devices, and the implications of findings for operational use, basis of issue, and search deployment, as well as for improvement of soldier effectiveness in using these devices.

Procedure:

135 operators (players) were tested at the rate of nine per night. They were required to search for targets over search areas defined by scan angles of 75°, 35°, and 25°. The area to be searched was a complex and heterogeneous terrain which extended to 1500 meters. Targets differing in type, contrast, and mode of presentation were placed in the area at distances of 100-1200 meters from the players. Testing was conducted under starlight, half-moon, and full-moon illumination. The devices used were the Starlight Scope (SS), Crew Served Weapon Night Vision Sight (CSWS), and the Night Observation Device, Medium Range (NOD). Detection responses and search behavior were recorded on magnetic tape.

Findings:

Prior research had indicated that operators failed to detect many targets that were within the device capabilities. The results of the present experiment showed that reduction in search area size greatly improved operator efficiency, particularly under low light conditions.

Effect of search area size on target acquisition was found to be related to target mode (static vs dynamic) and to distance. Moving and stationary targets were detected equally often when the search area was large, but with reduced area size more moving targets than stationary targets were detected. Reduction in size of search area increased the detection of distant targets more than it did of close targets. The SS and CSWS previously found to be of limited value for detection of targets at mid (350-800 meters) and far (800-1200 meters) distances improved considerably in this respect when the search area was narrowed.

Improvement resulting from increasing the number of devices used was greatest for wide search areas, particularly under low illumination. For all illumination conditions and search area sizes, increasing the number of operators with devices from one to two produced a sizable improvement. When the number of operators was increased from two to three, there was less improvement. When more than one operator was used, more targets were detected when overlapping search of the entire area was employed than when the area was divided into sub-sectors.

Utilization:

Soldiers' effectiveness with these devices is highly related to search area size, as well as to device deployment, number of operators, and individual operator efficiency. The findings show how performance is affected by environmental factors and target characteristics, and suggest how target acquisition can be improved by reduction in search area size and by the use of multiple properly deployed devices. To maximize the probability of target detection, when tactically feasible the search area should not be fractionated into smaller sub-sectors.

EFFECTS OF SEARCH AREA SIZE ON TARGET ACQUISITION WITH PASSIVE NIGHT VISION DEVICES

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BACKGROUND

The U. S. Army has given high priority to the development and fielding of advanced systems for surveillance, target acquisition, and night observation. The effectiveness of these systems is complexly determined by the interactions of the equipment, method of employment, and the human operator. The present publication describes research which is part of an on-going program designed to improve the effectiveness of the soldier during night operations and, in particular, his effectiveness with night observation devices and sensors. A primary goal of the program is to provide information which will aid in the solution of the following problems:

<u>Who should use night vision devices and sensors</u>? Individuals differ greatly in the ability to acquire targets with these devices. To what are these differences attributable? To what extent can these differences be reduced by training? What kind of training is effective? If selection of operators is necessary, on what basis should selection be made?

<u>How should the devices be used</u>? What are the proper search techniques? What are the implications of human capabilities and limitations for employment and deployment of men and devices--how large an area can a man effectively search? How long can a man use a device effectively? What are suitable work-rest cycles? If two men are to use devices, should the men be assigned separate or overlapping search sectors?

<u>Which devices should be used and under what conditions</u>? The devices differ in their characteristics and capabilities and are affected differently by changes in conditions. What is the relative performance with the devices under different light levels? On targets of different types? On targets at different distances? On different types of terrain? For different tactical applications?

<u>What should be the Basis of Issue (BOI) and Mix of devices</u>? How much is gained in target acquisition if two men with devices of the same type are used? If three men are used? How much is gained by the use of two or more men with different types of devices?

Answers to these questions provide information for operational employment, training, selection, and for the development of concepts, doctrine, and organization. Also, the information provided forms a basis for subsequent troop tests. From such experimentation, too, the parametric data essential for effective modeling and war games are obtained. In addition, determination of the complex interactions of the man, the device, and the operational situation provides valuable information for the design of future generations of devices.

The research described in the present publication involved the use of passive night vision devices. There is no doubt that these devices increase our combat capabilities. However, their level of effectiveness is dependent upon the conditions under which they are used, and upon how they are used. The primary purpose of the present experiment was to investigate the effects on performance of search area size--as it interacts with a number of environmental, target, and human factors--and to determine the implications of search area size for operational use, basis of issue, and search deployment of passive night vision devices. In addition, the experiment was designed to provide guidance for the development of work methods and procedures, search techniques, and methods of operational employment of the devices and thus further increase their effectiveness.

PROCEDURES

The devices tested were the Starlight Scope, AN/PVS-2 (SS), the Crew Served Weapon Night Vision Sight, AN/TVS-2 (CSWS), and the Night Observation Device, Medium Range, AN/TVS-4 (NOD). The primary variables were search area size, ambient light, and target distance, type, and mode (dynamic or static). These factors were selected from the large number of possible factors because previous research and pilot studies had indicated that they were especially critical determiners of performance. The parameters used for these factors were such as to permit the determination of device differences.

A total of 135 players were tested. Performance with all the devices was measured in a standard testing situation, or test bed; that is, all devices were tested simultaneously in the same environmental-target-terrain situation. The terrain used was flat to hilly, bisected by a road, traversed with ravines and streams, with some large open areas and some areas heavily cluttered with trees, brush, and rocks. Search areas were of three sizes defined by scan angles of 75°, 35°, and 25°. The area to be searched extended to 1500 meters. Targets were placed in this area at distances of 100 to 1200 meters from the players in three distance bands: 100-350 meters (near); 350-800 meters (mid); and 800-1200 meters (far). Personnel and vehicular targets were presented both stationary and moving. Targets in the first two distance bands were primarily personnel; in the far band, primarily vehicular. Target-background contrast was manipulated by placing targets against appropriate backgrounds. Testing was conducted under starlight, half-moon, and full-moon illumination.

Prior to testing, approximately 90 minutes of training were given. The purpose was to instruct the player in the use of his device, to teach him what the targets looked like when seen through a night vision device, and to allow him to develop facility in the rapid detection and simulated shooting of the targets. Training was given on an individual basis. No instructions on how to search were given, but each player was

told to use whatever technique he felt was most effective for him. In previous experiments this amount of training was found to be necessary, as well as sufficient in that increased practice on the devices produced no improvement in performance.

During testing the ability of the players to find targets through search was determined. Players were required to search for the same targets over search areas of three sizes, with all other factors held constant. Two measures of effectiveness were used: percentage of targets detected and time required to detect the targets. Target acquisition was recorded electronically. At the conclusion of testing of search performance, players were tested to determine how well they could see targets with their respective devices. This measure was used during subsequent analyses as a baseline for a measure of search efficiency.

FINDINGS AND THEIR IMPLICATIONS

Reduction in size of search area generally resulted in an improvement in target acquisition. However, the degree of improvement was affected by illumination, distance, and target mode, as well as by the number of operators using devices and how the men were deployed.

Search Area Size and Illumination

Reduction in size of the search area resulted in considerable increase in number of targets detected under starlight, but a much smaller increase under full moon. Amount of improvement varied according to the device. Under starlight, when the width of the search area was reduced from 75° to 25°, target detection with the SS, for example, went from 17% to 33%--an improvement of 94%; improvement with the CSWS was 54%, with the NOD 40%. When the area was reduced from 75° to 35°, the resulting improvement was somewhat smaller. Under high illumination, only the CSWS appeared to benefit from reduction in search area size when the targets were exposed for relatively long periods (two minutes), probably because the smaller field of view of the CSWS limits its capability for rapid search of a large area. With shorter target exposure times, the superiority of the smaller search areas increased dramatically for all devices under both starlight and full moon, but was greatest under starlight illumination. The time required for target detection was also less on the smaller search areas.

For operational use, these findings suggest that a reduction in search area size will considerably enhance performance by an increase in the percent detections and by a decrease in the time required for detection, and most noticeably for the SS and CSWS under low illumination conditions.

Search Area Size and Distance

Decreasing the width of the search area improved the detection of far targets more than it improved the detection of near targets, but the gain was a function of the specific device and the level of illumination. Under starlight, use of a narrow search area improved detection of near- and mid-range targets with all devices. With the NOD, the narrow search area also greatly improved the detection of targets beyond 800 meters (detection of far targets went from 17% on the 75° area to 40% on the 25° area). With the SS and CSWS, the trend was the same, but very few far targets were detected with these devices even on the narrow search areas (e.g., on the 25° area, 12% were detected with the SS and 7% with the CSWS). Thus, these devices were of very limited value under starlight illumination for detection of targets beyond 800 meters. Note, however, that no targets could have been detected under these conditions with the unaided eye. Under full moon, increasing distance did not impair performance as much as under starlight and the effects of search area size likewise decreased. Reduction in the width of the search area did not improve detection of near targets but did increase detection of the more distant targets. Although detection of targets beyond 800 meters was better with the NOD than with the other devices, substantial percentages of these targets were detected with the SS and CSWS and the differences among the devices were much less than under starlight.

For operational use it is suggested that, for targets beyond 800 meters, the search area be narrowed under starlight illumination and, if possible, that the NOD be used rather than the SS or CSWS; under high illumination, each of the devices is effective but narrowing the search area will still improve performance. In searching for near targets under starlight illumination, it is suggested that the search area be narrowed if possible, particularly for the SS; under high illumination, a wide area can effectively be covered by all devices except the CSWS.

Search Area Size and Target Mode--Static vs Dynamic

More moving than stationary targets were detected on the narrow search areas but not on the 75° area. This finding confirmed the hypothesis advanced in a previous report that the differential detection of dynamic and static targets was a function of search area size. According to this hypothesis, more dynamic than static targets should be detected in a narrow search area, but there should be no difference in detection in a wide search area. When operators are required to search a large area (for example, 75° wide and 1500 meters deep, as in the present experiment), they are more or less continuously moving their devices. Under these conditions, target movement is less conspicuous than under conditions in which the device is held more or less stationary, and a target moving within the device field of view produces an obvious disruption of a static environment. In the present experiment, it was expected that narrowing the search area from 75° to 25° or 35° would reduce the amount of device movement and thus facilitate the detection of moving targets, as was indeed found.

For operational use, when targets are expected to be moving rather than stationary, a narrower search area will result in a considerable increase in target detection, particularly under starlight illumination.

Search Area Size and Search Efficiency

In order to evaluate the efficiency of search, a technique was developed whereby target detection could be expressed in terms of the targets actually available--that is, "seeable"--to each man with his own device on a given night, rather than simply in terms of total targets presented. Theoretically, all the "seeable" targets could have been detected. An efficiency score of 100% would therefore mean that all the targets that could be seen were being detected, and further improvement in performance could be made only by improvement in the device itself.

Reducing the width of the search area improved efficiency considerably for all devices under low illumination (from an average of about 35% efficiency on the 75° area to about 60% on the 25° area). Under high illumination, only the CSWS benefited substantially from reduction in search area size, the efficiency with the other devices remaining at 65% to 70% regardless of size of search area.

For operational use, reducing the size of search area will improve efficiency under low illumination. However, substantial numbers of targets that are within device capabilities are not detected when a single operator is used. Use of multiple operators with devices should therefore be considered, particularly under low illumination.

Implications for Basis of Issue

Under starlight, increasing the number of operators with devices resulted in a considerable increase in detections with all devices and on all size search areas. Improvement was greatest on the 75° area but was large on all areas. With the SS, for example, 17% of the targets were detected by one man on the 75° area and 29% by two men--a gain of 71%; on the 25° area, 33% were detected by one man and 47% by two men--an improvement of 42%. For all search areas, the greatest increase in percent detections occurred when the number of operators was increased from one to two, but the increase was also substantial when the number of operators was increased from two to three. With the CSWS on the 75° area, for example, 26% of the targets were detected by one operator, 38% by two (a gain of 46%), and 50% by three (a gain of 32% over detections by two operators).

Under full moon, search area size was generally of relatively little importance and increasing BOI produced less relative increase in percent detections than under starlight; however, detection time was

reduced considerably by increased BOI on all size search areas. As performance under full moon was extremely high using two operators (generally around 80% detections or better), addition of a third operator did not greatly improve performance, even when the search area was large.

For operational use, when tactically feasible, two devices covering the same search sector should be used, particularly when the area to be covered is large and when the light level is low.

Implications for Search Deployment

When the tactical situation dictates that a wide search area be covered and when several men are available, how can they be most effectively used? Specifically, should the total area be divided into essentially non-overlapping sub-sectors with one man assigned to search each sub-sector? Or should the local commander, to the extent that the tactical and terrain situation permits, maximize overlap and have all available men simultaneously search the entire area?

The data were analyzed to determine the best techniques for use of two men and three men, assuming that the total area to be covered was 75° wide. In all cases, percentage of targets detected was higher with overlapping search sectors.

For operational use, it is suggested that a search area should <u>not</u> be fractionated into smaller sub-sectors. To maximize the number of targets detected, all men should whenever possible search the entire area.

CONCLUSIONS

Target acquisition is improved by reduction in size of search area, and use of two or three properly deployed operators with devices further increases effectiveness. However, the use of several operators is costly, in terms both of most effective utilization of available manpower and of the actual monetary cost of equipping men with suitable devices. The search efficiency of the individual operator was shown to be low, thereby imposing the need for reduction in the size of the search area and the use of several men with devices in order to increase the probability of target acquisition. If the effectiveness of the single man/device system could be substantially increased, fewer operators would be needed to reach the same level of effectiveness. The security and combat effectiveness of a unit would be improved with, at the same time, large savings in manpower resources and money.

TECHNICAL SUPPLEMENT

EFFECTS OF SEARCH AREA SIZE ON TARGET ACQUISITION WITH PASSIVE NIGHT VISION DEVICES

EXPERIMENTAL PROCEDURE AND DETAILS OF RESULTS

The experiment reported here is part of an on-going research program which has as its purpose the improvement of the effectiveness of the American soldier during night operations and, more specifically, his effectiveness with night vision devices and related sensors. As the effectiveness of any system is complexly determined by the interactions of the equipment, its method of employment, and the human operator, an attempt is made to consider all of these factors in the experiments conducted. At the same time, the attempt is made, by the use of appropriate scientific and statistical techniques, to define the contribution of the various subsystem elements to total system effectiveness so that areas in which improvement will substantially improve overall effectiveness can be identified. In all this research, the experiments are designed to produce results of practical importance for operational use, for training, and for the development of concepts, doctrine, and organization.

In this technical supplement both experimental procedure and results are reported in considerable detail. Step-by-step procedures, briefings, training schedules and techniques, etc., were reported in an earlier publication.[1]

EXPERIMENTAL PROCEDURE

Equipment

Night Vision Devices Tested. Image intensifiers of three different types were used: the Starlight Scope, AN/PVS-2 (SS); the Crew Served Weapon Night Vision Sight, AN/TVS-2 (CSWS); and the Night Observation Device, Medium Range, AN/TVS-4 (NOD).

The Data Acquisition System. The data acquisition system has three components: 1) the tripods which support the universal device platforms (UDPs) and the night vision devices; 2) the universal device platforms; and 3) the electronic control and data recording console. Nine heavy-duty tripods are used in line, each tripod being set in concrete for stability. Each UDP consists of a metal casing attached to the tripod head, the night vision device being attached to the UDP (Figure 1). The UDP rotates with respect to a fixed base and is adjustable for elevation.

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[1] Sternberg, Jack J. and James H. Banks. Search effectiveness with passive night vision devices. BESRL Technical Research Report 1163. June 1970.

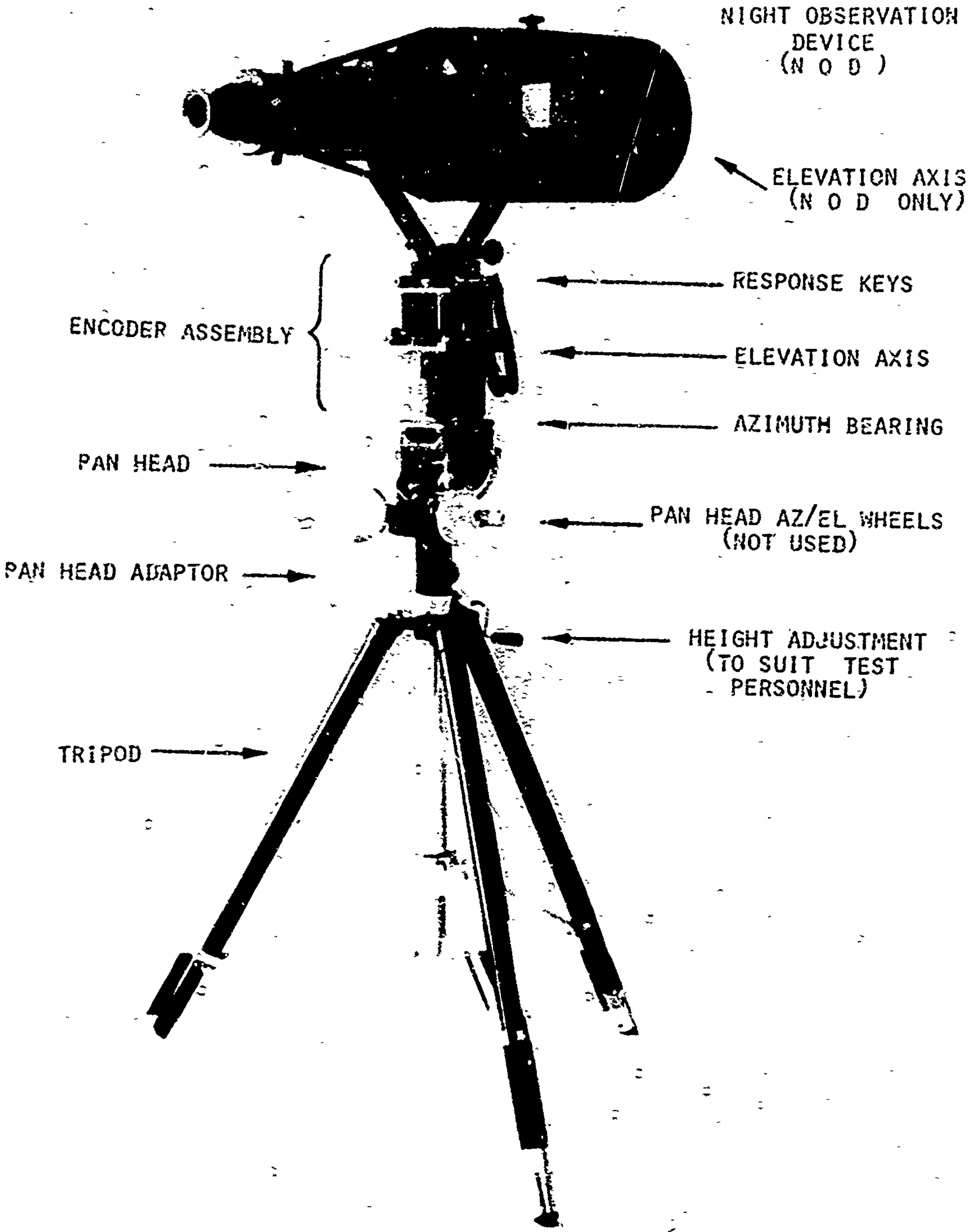

Figure 1. Universal Device Platform (UDP)

Each UDP contains two shaft encoders, one for azimuth and one for elevation, which indicate to within 0.1° the orientation of the instrument (Figure 2). Each UDP also contains a "trigger" microswitch which the player presses when he acquires a target. These microswitches are designed and located so that their use does not interrupt searching or disturb orientation of the device. Output from the microswitch and shaft encoders is transmitted by cable to the data recording console. At the base of the UDP there is a metal collar with a series of holes spaced every 5°. Pins are inserted in these holes to mechanically restrict search area size. For the present experiment, the search areas were restricted to 75°, 35°, and 25°.

The electronic control and data recording console (Figure 3) is van-mounted and contains a monitoring control panel and a recorder panel. On the monitoring control panel are a magnetic tape unit, numerical displays (NIXIE[2] tubes) for visual presentation of azimuth and elevation of selected subject stations on a real-time basis, and a number of selection buttons. Information recorded on the magnetic tape includes the beginning and end of target presentation, player number, azimuth and elevation of the device used (sampled four times per second), and any responses by a player. A time base is provided by tape speed. Thus, both target acquisition responses and detailed recording of search behavior are on the tape and extractable by computer. The recorder panel contains a digital recorder which provides on a near real-time basis a graphic hard-copy display of the search behavior, target coordinates, and responses of any selected player.

Ancillary Equipment. The communication system includes land line telephones between control and personnel targets; radio communication between control and vehicular targets; telephone lines between control, engineer in van, and target monitor; and a two-way speaker system between control and the player cubicles.

Photometric readings were obtained with a Gamma Scientific Corporation Model 2020 photometer,[3] with S-11 photocathode and cosine-filter which gave an integrated reading, in footcandles, of illumination from the upper hemisphere. Readings were taken at regular intervals throughout the experiment.

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[2] Commercial designations are used only for precision in describing the experiment. Their use does not constitute indorsement by the Army or by the Behavior and Systems Research Laboratory.

[3] See footnote 2.

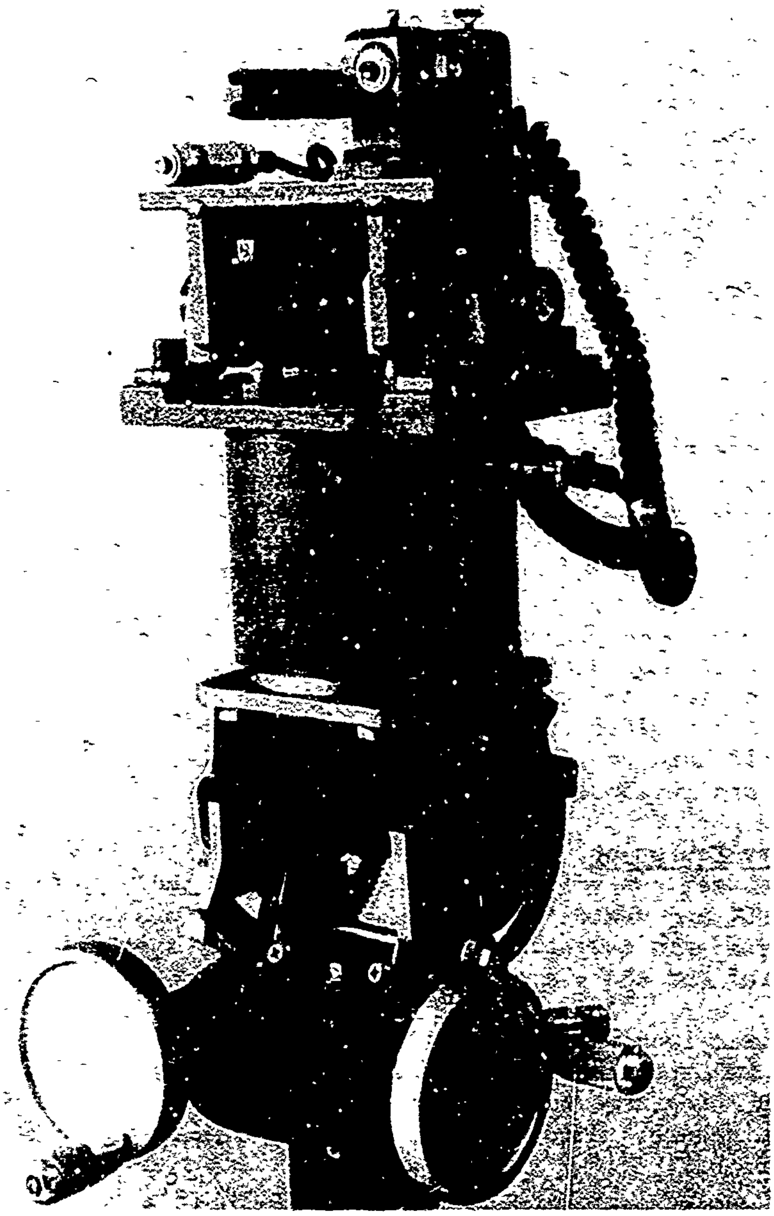

Figure 2. Enlarged View of Shaft Encoder Assembly Portion of UDP
(Shows Response Buttons)

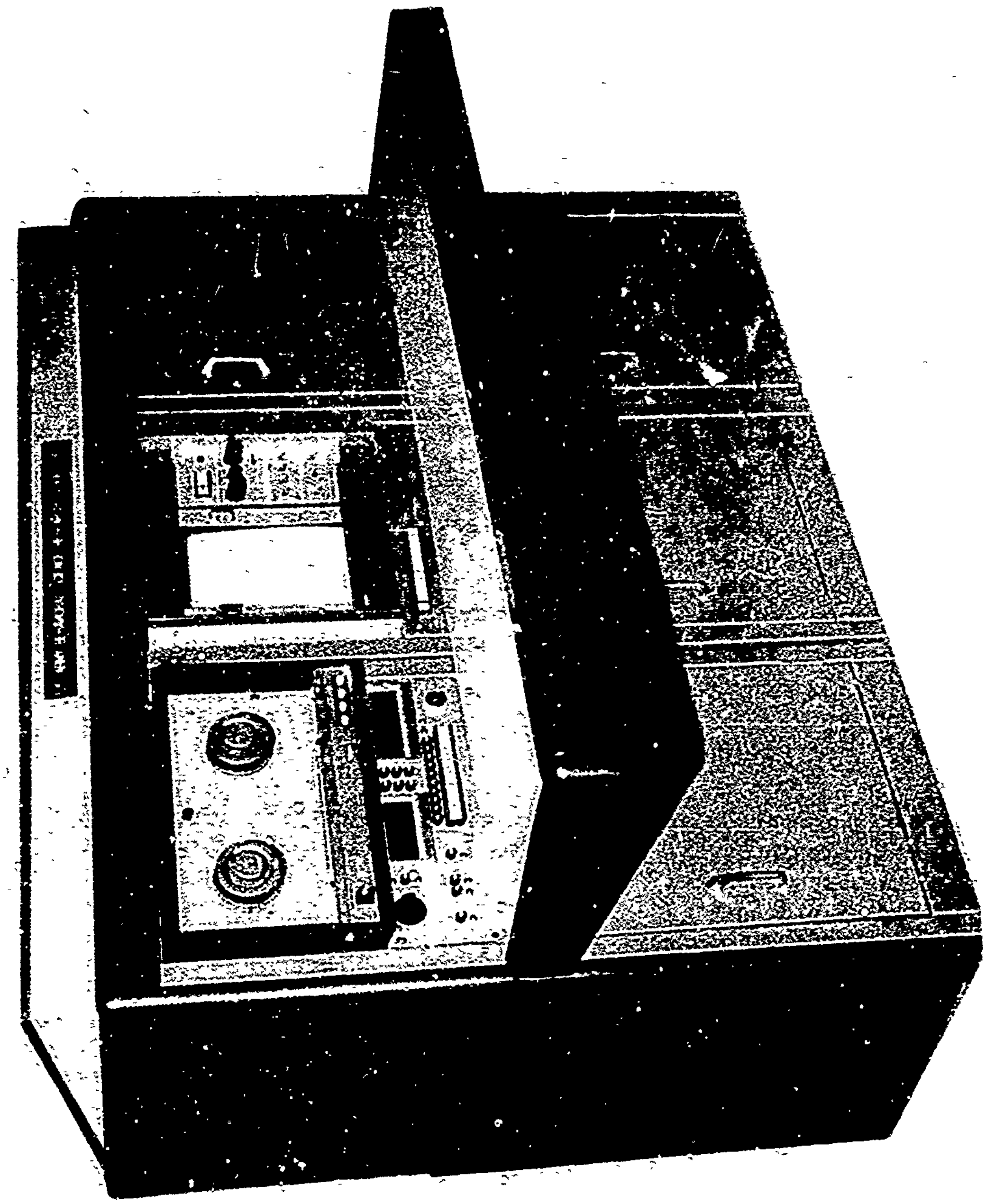

Figure 3. Monitoring-Control Console

Terrain

The terrain was part of the Hunter Liggett Military Reservation. In selecting the terrain, many factors had to be considered. The experiment required terrain of considerable size, suitable for a wide variety of experimentation. The terrain selected permitted the use of a search area approximately 75° wide and over 1500 meters deep. A complex terrain was needed in order to provide a realistic search situation. The area selected was flat to hilly, bisected by a road, traversed by ravines and streams, with some large open grassy areas and some areas heavily cluttered with trees, brush, and rocks. Because the devices being tested were of the light intensification type, good control of illumination was essential. The test area was surrounded by mountains, the nearest town of any size (though small) being some 30 miles distant. Skyglow was therefore effectively eliminated. Additionally, the terrain had a general north-south orientation, the moon passing over the terrain roughly from right to left. Thus, when testing was done under moonlight, targets were not frontlighted during one portion of the session and backlighted during a later portion. (Previous research has shown that the probability of detection changes considerably for front versus back lighting.) Figure 4 shows a portion of the terrain and the test cubicles. Figure 5 is a schematic drawing of the test control center looking back from the terrain.

Targets

Thirty-six target locations were used in the testing session. All targets could be seen by the unaided eye during daylight. Targets at each location were presented once in dynamic and once in static mode, giving 72 target presentations per evening. The 36 targets were of two types--24 personnel and 12 vehicular. Vehicles were of three types: ¼-ton truck, 5-ton truck, and armored personnel carrier (M-113). The personnel targets were soldiers dressed in fatigues, apppearing either singly or in groups of two. The targets were of varying difficulty, and were distributed throughout the terrain at distances of 100-1200 meters from the test stations. Targets were located in three bands: 100-350 meters (near distance); 350-800 meters (mid distance); and 800-1200 meters (far distance). As the effect of search area size was being evaluated, an additional constraint was imposed upon target location: Targets were positioned so that each sector (three of 25°, two of 35°) of the 75° field had an equal number of targets of equivalent types (personnel-vehicular; static-dynamic; high-low contrast; and near-mid-far distance).

Figure 4: Left Half of Terrain Forming the Target Area (Shows Player Test Cubicles in Foreground)

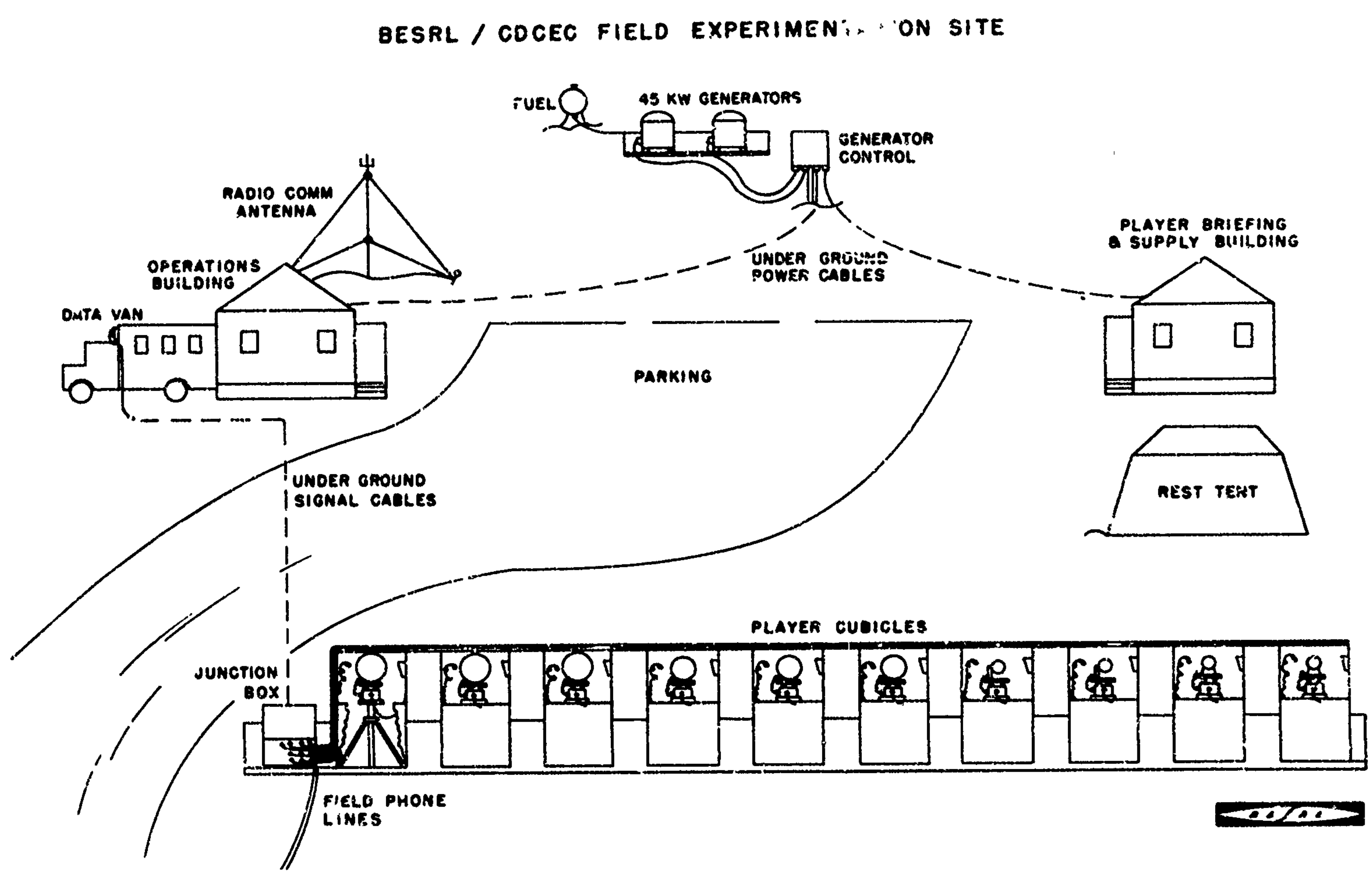

Figure 5. Schematic Drawing of Test Control Center Looking Back from Terrain

Contrast was manipulated by placing targets against suitable backgrounds--silhouetted against a tree line (low contrast) or against an open grassy area (high contrast)--but no attempt was made to rigorously define or measure target-background contrast. Placement of targets was carefully controlled so that target visibility remained constant for a given evening; e.g., changes in moon angle did not throw a shadow on a target during one part of a night's run. A complete description of the targets appears in Table 1.

Ambient Illumination Conditions

Testing was conducted under three ambient illumination conditions: starlight, half moon, and three quarter to full moon. The range and mean photometric readings (in footcandles) obtained under each of these conditions are given below.

Starlight: 7.8×10^{-5} to 1.4×10^{-4}; mean = 1.1×10^{-4}

Half Moon: 3.1×10^{-3} to 5.0×10^{-3}; mean = 4.3×10^{-3}

Full Moon: 5.7×10^{-3} to 1.5×10^{-2}; mean = 9.1×10^{-3}

Testing Procedure

Subjects. The subjects, or players, were 135 enlisted men from the Experimentation Battalion (Armor), Camp Roberts, California, and the Experimentation Battalion (Infantry), Hunter Liggett Military Reservation, California. Nine different players were tested per night, three on each of three devices. Each player was required to search two sectors, 75° and 25°, 75° and 35°, or 35° and 25°. Table 2 reflects the number of players tested for each search area sector (not the total number of players, since each player was tested on two sectors). It also reflects cases which were deleted because of administrative and technical difficulties.

Orientation of Players. When players arrived at the test site, they were brought into a briefing tent without being permitted to study the terrain. No players had had prior experience on the particular terrain used. Designated military personnel explained to the players the importance of the research. A civilian scientist then explained their role as players and described what they would be doing during the night. Players were then taken into the Experimental Control Center, where the equipment and its functions were described to them. These briefings had two purposes: first, to increase the players' interest and involvement in the the experiment and, second, to explain how and why their performance with the devices would be monitored throughout the evening. This combination of approaches was effective in eliciting their cooperation and sustained participation.

Table 1

DESCRIPTION OF TARGETS

Target[a]	Type	Azimuth	Elevation[b]	Slant Distance[c]	Range[d]	Search Area Sectors[e] 25°	35°
01A	1 Man	3.1	.9	281	Near	Left	Left
02A	1 Man	27.6	-1.0	97	Near	Center	Left
03A	1 Man	59.2	.6	228	Near	Right	Right
04A	1 Man	4.3	1.2	515	Middle	Left	Left
05A	1 Man	26.9	.4	299	Near	Center	Left
06A	1 Man	44.3	.6	270	Near	Center	Right
07A	2 Men	2.4	4.0	707	Middle	Left	Left
08A	2 Men	18.6	4.6	733	Middle	Left	Left
09A	Jeep	5.8	4.1	695	Middle	Left	Left
10A	APC	15.1	8.5	938	Far	Left	Left
11A	5 Ton	5.7	7.4	1003	Far	Left	Left
12A	APC	16.0	4.4	710	Middle	Left	Left
01B	1 Man	7.0	-0.1	165	Near	Left	Left
02B	1 Man	44.1	-1.4	108	Near	Center	Right
03B	1 Man	64.9	2.2	187	Near	Right	Right
04B	1 Man	11.1	0.5	251	Near	Left	Left
05B	1 Man	28.5	0.5	281	Near	Center	Left
06B	1 Man	57.2	1.9	286	Near	Right	Right
07B	2 Men	40.1	1.9	485	Middle	Center	Right
08B	2 Men	31.7	4.0	765	Middle	Center	Left
09B	Jeep	28.1	4.2	701	Middle	Center	Left
10B	APC	30.0	5.1	722	Middle	Center	Left
11B	5 Ton	44.9	6.8	1032	Far	Center	Right
12B	APC	45.3	6.5	1028	Far	Center	Right
01C	1 Man	22.2	-0.5	176	Near	Left	Left
02C	1 Man	53.1	-0.5	156	Near	Right	Right
03C	1 Man	66.5	1.2	187	Near	Right	Right
04C	1 Man	16.5	0.2	272	Near	Left	Left
05C	1 Man	38.1	0.4	391	Middle	Center	Right
06C	1 Man	61.6	3.2	301	Near	Right	Right
07C	2 Men	56.4	3.4	350	Middle	Right	Right
08C	2 Men	64.3	6.1	885	Far	Right	Right
09C	Jeep	68.3	6.3	910	Far	Right	Right
10C	APC	63.1	8.0	1091	Far	Right	Right
11C	5 Ton	57.1	6.0	919	Far	Right	Right
12C	APC	56.5	6.7	977	Far	Right	Right

[a] Target numbers are sequential. For a given test scenario, targets were presented in an order which counterbalanced all target characteristics and search area sizes.

[b] Plus or minus reflects displacement from the calibration zero point: up (+); down (−).

[c] Slant distance to nearest meter.

[d] Range denotes distance category: Near, 100-350; middle, 350-800; and far, 800-1200 meters.

[e] Search area sector describes the location of the targets within a 25° or 35° sector. The targets are designated as left, center, and right for the 25° sector, and left and right for the 35° sector.

Table 2

NUMBER OF PLAYERS BY SEARCH AREA SIZE (SECTOR)
AND ILLUMINATION CONDITION

Device	Search Sector	Illumination Starlight	Half Moon	Full Moon
SS	75°	12	6	11
	35°	11	6	12
	25°	11	6	11
CSWS	75°	10	6	11
	35°	5	6	12
	25°	5	6	11
NOD	75°	12	6	12
	35°	12	6	12
	25°	12	6	12

Training. Following the briefings, players were assigned to specific devices, and training was begun. The training session had three purposes: 1) to instruct the player in the use of his device; 2) to teach him the appearance of targets when viewed through a night vision device; and 3) to allow him to develop facility in rapid detection and simulated shooting of the targets. Training did not commence until at least the End of Evening Nautical Twilight (EENT), with the sun 12° or more below the horizon. The training session was conducted by the test director, with the engineer at the monitoring control console and nine instructors who assisted the players individually. The test director first read a prepared script of general instructions. When the instructions became specific to the device, the individual instructor instructed the players, reading from a prepared script. The instructions covered tripod height adjustment, diopter adjustment, objective lens focusing, limits of the search sectors, and procedures to be followed in shooting the targets. No instructions or training on search techniques were given, but the players were told that during testing each should use whatever technique was best for him.

When all adjustments had been made and the players understood how to use the device, the second phase of training began. Five targets were presented, one at a time. Prior to presentation of each target, the players were told the type of target, its location, and that it would be lighted. The players were instructed to find the light and to shoot it. After all players had found and shot the target, the light was extinguished, and the players were instructed to study and shoot

the target again if they could see it. The engineer at the monitoring control console compared player responses with a catalog of actual target locations and informed the test director which players were having difficulty in finding the targets or were not following proper procedures. When all players had successfully responded to each of these five targets, eight additional targets were presented, one at a time. For these targets, the players were not told the target location, but the target again was lighted. After most players had found and shot the lighted target, the light was extinguished and the players were instructed to study and shoot the target again if they could see it. Players having difficulty were assisted by their instructors.

The purpose of the third phase of training was to provide practice in rapid acquisition of targets so that subsequent performance during testing would not be influenced by additional learning. Thirteen targets were presented, following the same procedure as during testing, and no assistance, either by lighting of targets or instruction, was given. At the conclusion of training, players were given a 15-minute rest prior to the beginning of testing.

Total training time was approximately 90 minutes (15, 30, and 45 minutes for parts 1, 2, and 3, respectively). This highly structured training session had been found in previous research to be both necessary for adequate training in a reasonable amount of time and sufficient in that no further improvement resulted from additional use of the devices. While training was performed on the same terrain used for testing, the practice target locations were different from the experimental target locations.

Testing

Testing did not commence until after the End of Evening Astronomical Twilight (EEAT), when the sun is 18° or more below the horizon, and was terminated prior to the Beginning of Morning Astronomical Twilight (BMAT), before the sun approaches 18° below the horizon. Testing was scheduled so that the ambient illumination on any given night remained relatively constant--for example, on a half-moon night, data were collected only when the half moon was exposed. When testing was conducted under moonlight conditions, data collection did not commence until the moon had ascended to 25° above the eastern horizon and was terminated before the moon descended beyond 25° above the western horizon. These procedures minimized ambient illumination changes during any given evening.

The testing phase of the experiment was divided into two parts. The first part was to determine the ability of players to find targets through search. The second part was to determine the ability of each man-device combination to see targets without search.

Search. Players were required to search the terrain continuously for six periods of 30 minutes each. During each period, 12 targets were exposed for two minutes per target with approximately 30 seconds between target presentations. For the 75° search, 12 targets appeared randomly throughout the entire area, or 75° sector; for the 25° sector, 4 targets appeared randomly (over each of three 10-minute periods) within each of the 25° sectors; and for the 35° sector, six targets appeared randomly (over each of two 15-minute periods) within each sector. (For the 25° and 35° sectors, the mechanical stops were adjusted so that each player was searching the appropriate area.) At half-hour intervals, players were given a five-minute break in place. At one-hour intervals, they were given a 15-minute break, during which they were brought into the tent where they could smoke, warm up, and get coffee. During this break the targets were relocated.

In each block of 24 presentations, each of 12 targets was presented twice, once in dynamic and once in static mode; the twelve targets were presented six moving and six stationary. After a short rest break for the players, the 12 targets were presented again, but this time the players were assigned a different search area size with the targets in the same location, but in reversed mode. All dynamic targets moved parallel to the line of player cubicles, that is, across the line of sight of the players as they searched the field. Personnel targets moved at a walking pace and vehicular targets at three or four miles per hour. The movement of each target was 1° of visual arc, the actual length traversed being adjusted according to the distance of the target from the players. Three basic sequences (scenarios) of target presentations were used, with two movement subsequences (subscenarios) under each. Each scenario contained targets of all types, distances, and contrasts. Order of scenarios was systematically varied to counterbalance sequential effects. Usually, only one target was presented at a time (a multiple-man personnel target being defined as a single target), but three times in each subscenario additional targets, which were not scored, were presented simultaneously to reduce the possibility that players would learn that only single targets were presented. To prevent players from using vehicular engine noise as a cue, three times in each subscenario one of the vehicular targets which was not exposed would run its engine for 30 seconds.

For the entire evening's run, targets were continuously observed by the target monitor on the test line. The monitor was equipped with a NOD and was thoroughly familiar with all target locations and the order of the scenarios being used on a given night. His primary responsibility was to verify that targets were up and down at the correct time, in the correct locations, and in the correct movement modes. In most cases, a one-word verification immediately followed target report. This procedure was utilized to maintain discipline and responsiveness of target personnel. Additional responsibilities of the monitor included reporting of light security violations, improper concealment of targets, and changes in ambient illumination and weather conditions.

Player behavior was continuously monitored by the instructor assigned to each player and by the training NCO and a civilian scientist also on the test line. In addition, an engineer at the monitoring control console continuously monitored visual displays (NIXIE tubes) showing real-time azimuth and elevation of each instrument, to insure that all players were searching and following correct procedures.

For purpose of analysis, a player response was defined as a "hit" when the azimuth and elevation of the instrument were within ±3° of the actual target location. The target detection data reported are based on this definition.

<u>See</u>. Upon completion of the search phase of testing, the final 12 targets were presented again to determine the ability of each man-device combination to <u>see</u> targets when no search was involved. On each trial, a light was turned on the target, and the players were told the target location and type. Players were instructed to find the lighted target; after the lighted target was found, the light was extinguished. The players were told to continue to watch the target (if they could see it) and to fire on it as soon as it started to move into defilade. Targets moved into defilade at varying times (unknown to the players) after the light was extinguished: 20 seconds for near targets, 40 seconds for mid targets, and 60 seconds for far targets. The player was scored as having seen the target if he fired while the target was moving into defilade or within eight seconds of target disappearance. Performance on this test was used during subsequent analyses as a baseline for a measure of search efficiency.

RESULTS

The primary purpose of the present experiment was to determine the relationship between search area size and performance. More specifically, the results deal with how performance on differing search area sizes is affected by environmental, target, employment, and human factors. The environmental and target factors considered are illumination, distance, and target mode (static vs dynamic). The deployment factor considered is overlapping vs non-overlapping search sectors. Search efficiency was examined to determine implications for improvement of human performance and for basis of issue. Main effects and interactions of these factors are discussed in terms of two measures of effectiveness--percentage of targets detected and time required for target detection. The three devices studied were the Starlight Scope (SS), Crew Served Weapon Night Vision Sight (CSWS), and the Night Observation Device, Medium Range (NOD).

Two tests were administered to determine their possible value as selection measures--the Army Night Seeing Test, designed to measure night vision; and a "hidden figures" test, in which the subject has the task of finding a given figure "hidden" in a more complex figure--a task conceptually similar to that of discriminating a target "hidden" in a complex background. However, performance on neither test correlated significantly with performance on the night vision devices.

Search Area Size and Illumination

Percent Detection. In general, the reduction of search area size resulted in a considerable increase in targets detected under starlight conditions and an almost negligible increase under full-moon conditions; however, the amount of increase varied according to the device and to the target exposure time. The effects of illumination on percent detection with the three devices for the three search sectors are shown in Table 3. As expected, for each device and for each search sector size, increased illumination resulted in improved performance. However, under the half-moon condition, target detection was found to be highly similar to that under the full-moon condition.

Table 3

PERCENT TARGET DETECTION UNDER VARYING CONDITIONS OF AMBIENT LIGHT

Device	Search Sector	Ambient Light Level		
		Starlight	Half Moon	Full Moon
SS	75°	17	56	58
	35°	25	64	69
	25°	33	59	64
CSWS	75°	26	31	47
	35°	34	61	67
	25°	40	57	66
NOD	75°	40	59	66
	35°	54	71	69
	25°	56	67	69

Under the starlight condition with the SS, an improvement of 94% was found in going from 75° (17% detection) to 25° (33% detection). With the CSWS and the NOD, improvement was somewhat less dramatic, but still very substantial (54% and 40%, respectively). When the search sector was narrowed to 35° instead of 25°, a considerable increase in detections was still found; however, improvement was less (47%, 31%, and 35% for the SS, CSWS, and NOD, respectively). Thus, the importance of search sector size under low illumination is obvious: reduction in size of search sector results in a higher percentage of target detection, especially with the SS.

Under full-moon illumination, only the CSWS appeared to benefit greatly from reduction in search sector. This finding was not unexpected. In a previous experiment[4] in which a 75° sector was used, search performance with the CSWS was consistently inferior to that with the SS, the largest differences being under full moon. In the report, it was suggested that the smaller field of view of the CSWS, in comparison to that with the SS, probably limits the capability of the CSWS for rapid search of a large area, hence lowering its effectiveness, and that performance with the CSWS should be greatly improved when a smaller search sector was used. In the present experiment, it was expected that target acquisition with the CSWS would be equal or superior to that with the SS on the small search sectors but inferior to that with the SS on the 75° sector, expecially under full moon. This hypothesis was in part confirmed. Although performance with the CSWS was somewhat better than with the SS under starlight illumination, under full moon it was inferior to that with the SS on the 75° sector, performance with the two devices being equal on the smaller areas. The balance of evidence would seem to justify two conclusions: first, use of the CSWS does not improve target acquisition capability over that with the SS. Second, with a large search sector, the search effectiveness with the CSWS is probably inferior to that with the SS. For maximum search effectiveness, therefore, the search sector assigned to an operator with a CSWS should be smaller than that for operators with a SS or a NOD.

The results just reported were based on targets exposed for 120 seconds--the actual target exposure time used in the present experiment. For shorter exposures, the superiority of the smaller search sectors, in comparison to the 75° search sector, increased dramatically. Table 4 shows for each search sector size the percent detections made within 30, 60, and 90 seconds after target presentation, as well as for the full 120 seconds. In addition, the superiority of the smaller search sectors to the 75° sector is shown for each target exposure time. With the NOD under full-moon illumination, for example, when the targets were exposed for 120 seconds, 66% of the targets were detected on the 75° sector and 69% on the 25° sector. Thus, target detections showed improvement of 5% when the search sector was reduced from 75° to 25°. However, during only the first 30 seconds of target presentation, 24% of the targets were detected on the 75° sector and 41% on the 25° sector--an improvement of 71%.

To summarize, reduction in size of search sector results in considerable improvement under starlight illumination in the probability of target detection, and small improvement under full-moon illumination. With shorter target exposures (30, 60, and 90 seconds), the improvement resulting from use of smaller search sectors is large under either illumination condition.

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[4] See footnote 1, page 9.

Table 4

PERCENT DETECTION AND SUPERIORITY OF SMALLER SEARCH SECTORS TO THE 75° SEARCH SECTOR FOR VARIOUS TARGET EXPOSURE TIMES

Device	Target Exposure Time (Sec)	Starlight					Full Moon				
		% Detection Search Sector Size			Superiority		% Detection Search Sector Size			Superiority	
		75°	35°	25°	35°	25°	75°	35°	25°	35°	25°
SS	120	17	25	33	47	94	58	69	54	19	10
	90	13	21	27	62	108	50	62	59	24	18
	60	7	17	21	143	200	40	54	52	35	30
	30	a	a	a	a	a	21	37	33	76	57
CSWS	120	26	34	40	31	54	47	67	66	43	40
	90	22	25	34	14	55	39	61	60	56	54
	60	18	22	27	22	50	29	48	46	66	59
	30	11	12	19	9	73	13	29	31	123	138
NOD	120	40	54	56	35	40	66	69	69	5	5
	90	35	46	50	31	43	55	64	66	8	12
	60	25	39	41	56	64	46	55	60	20	30
	30	14	21	25	50	79	24	37	41	54	71

[a] Insufficient data.

Target Detection Time. The effects of search sector size and illumination on average target detection time are shown in Table 5. (Times are based only on targets actually detected.) In general, decreasing search sector size and increasing illumination both reduced the time required for target detection. For the 75° area, average time varied from 46 to 62 seconds (depending upon the device) under starlight, and from 46 to 55 seconds under full moon. For the 25° area, the range was 42 to 52 seconds under starlight and 32 to 42 seconds under full moon. In general, there was little difference between the two smaller search sectors but detection time for both was somewhat less than for the 75° area. With the SS, for example, the time was 50 seconds and 52 seconds for the 35° and 25° sectors under starlight, and 62 seconds for the 75° search sector. Under full moon, the values were 38 and 37 seconds for the 35° and 25° sector, and 47 seconds for 75°.

Table 5

TARGET DETECTION TIME UNDER VARYING CONDITIONS
OF AMBIENT LIGHT
(In Seconds)

Device	Search Sector	Ambient Light Level		
		Starlight	Half Moon	Full Moon
SS	75°	62	47	47
	35°	50	39	38
	25°	52	36	37
CSWS	75°	46	59	55
	35°	54	45	43
	25°	43	42	42
NOD	75°	50	53	46
	35°	46	31	36
	25°	42	45	32

Tables 6 and 7 show in more detail the relation of target detection and time. For each table (75° and 25° search sectors, respectively), the cumulative percent of targets detected is shown by 15-second blocks. Thus, all the targets (100%) that were going to be detected were detected by 120 seconds, the maximum time of target exposure. 80% to 90% of the targets that were going to be detected were detected within 90 seconds after target presentation. Thus, extending target exposure time beyond 90 seconds resulted in relatively little improvement in performance.

Table 6

CUMULATIVE PERCENTAGE OF TARGETS DETECTED: 75° SECTOR SIZE
(By 15-Second Blocks)

Ambient Light Level	Device	Time in Seconds 0-15	16-30	31-45	46-60	61-75	76-90	91-105	106-120
Starlight	SS	11	21	32	44	61	77	86	100
	CSWS	19	42	60	68	76	83	92	100
	NOD	18	34	47	62	74	87	96	100
Full Moon	SS	16	36	55	70	81	87	95	100
	CSWS	13	27	42	61	71	82	92	100
	NOD	17	37	57	70	83	89	94	100

Table 7

CUMULATIVE PERCENTAGE OF TARGETS DETECTED: 25° SECTOR SIZE
(By 15-Second Blocks)

Ambient Light Level	Device	Time in Seconds 0-15	16-30	31-45	46-60	61-75	76-90	91-105	106-120
Starlight	SS	11	29	49	63	76	84	90	100
	CSWS	23	49	60	67	81	87	96	100
	NOD	22	45	60	74	82	89	93	100
Full Moon	SS	25	52	69	82	89	93	96	100
	CSWS	23	47	62	70	82	90	95	100
	NOD	25	59	73	87	92	95	97	100

Operational Implications. For operational use, these findings suggest that search sector size should be reduced for the SS and CSWS, especially under low ambient illumination. Use of a smaller search sector will increase the probability of target detection and decrease the time required to detect a target.

Effect of Search Sector Size and Distance

In the present experiment three distance bands were used: 100-350 meters (near); 350-800 meters (mid); and 800-1200 meters (far). In interpreting the results discussed in this section, it should also be remembered that the targets in the first two distance bands were primarily personnel and in the far distance band primarily vehicular. The effects of distance on percent detection and target detection time are shown in Tables 8 and 9. As performance under half and full moon was very similar and as the number of players tested under half moon was too small to permit the more detailed comparisons, for these and subsequent tables only two illumination levels--starlight and full moon--will be shown.

Percent Detection. The effects of distance on percent target detection with the various devices on the three search sector sizes are shown in Table 8. In general, decreasing the width of the search sector improved the detection of distant targets more than it improved the detection of near targets. However, this gain was a function of the specific device and the illumination level. With the NOD under starlight, for example, 60% of the near targets were detected on the 75° sector and 74% on the 25° sector--an improvement of 23%. For the far targets, 17% were detected on the 75° sector and 40% on the 25° sector--a relative improvement of 135%. Thus, the probability of detecting targets at distances of greater than 800 meters with the NOD was greatly enhanced by the use of a small search sector. With the SS and CSWS the trend was the same but the number of targets detected at distances of 800-1200 meters was very small. For example, with the SS, 2% of the far targets were detected on the 75° sector and 12% on the 25° sector. Thus, the SS and CSWS were of very limited value under starlight illumination for detection of targets beyond 800 meters, but it is worth noting that no targets could have been detected under these conditions with the unaided eye.

Under full-moon illumination, increasing distance did not impair performance as much as under starlight. The effects of search sector size and the differences among the devices likewise decreased. For near targets (less than 350 meters), decreasing the width of search sector did not improve performance with the SS and NOD. For far targets, however, performance was improved on all of the devices when the search sector was narrowed, but improvement was less than under starlight. Also, the SS and CSWS were of considerable value for detection of targets at 800-1200 meters.

Table 8

PERCENT TARGET DETECTION BY DISTANCE AND LIGHT LEVEL

Device	Search Sector	Ambient Light Level: Starlight Near	Starlight Mid	Starlight Far	Full Moon Near	Full Moon Mid	Full Moon Far
SS	75°	29	11	2	72	51	38
	35°	36	23	8	74	67	63
	25°	55	20	12	79	53	48
CSWS	75°	48	13	4	54	47	32
	35°	54	25	10	71	73	51
	25°	68	27	7	78	63	45
NOD	75°	60	31	17	79	59	49
	35°	67	43	45	71	70	64
	25°	74	45	40	75	64	61

Target Detection Time. Average target detection time, in seconds, is shown in Table 9. Target detection time was, in general, longer for the more distant targets. Also, when the width of the search sector was reduced, the time required for detection of near targets was, in general, reduced. Under starlight, detection times for near targets varied between 45 and 61 seconds, depending upon the device, for the 75° sector, and between 32 and 47 seconds for the 25° sector. Under moonlight, the range for near targets was 45 to 58 seconds on the 75° sector and 29 to 35 seconds on the 25° sector. However, the time required for detection of mid and far targets showed no consistent trend when search sector size was reduced. Under full moon, for example, detection time for far targets varied between 47 and 60 seconds on the 75° sector and between 41 and 60 seconds on the 25° sector. Thus, use of a small search sector did result in more rapid detection of targets at distances up to 350 meters, but did not consistently improve the speed of detection of more distant targets.

Operational Implications. In searching for targets at distances beyond 800 meters under starlight illumination, it is suggested that the search sector be narrowed, and if possible, that the NOD be used rather than the SS or CSWS. Under high illumination, each of the devices is effective, but use of a narrower search sector will still result in improved performance. In searching for near targets, under starlight illumination, it is suggested that the search sector be narrowed if possible, particularly for the SS; under high illumination a wide sector can effectively be covered by all devices except the CSWS.

Table 9

TARGET DETECTION TIME BY DISTANCE AND LIGHT LEVEL
(In Seconds)

Device	Search Sector	Ambient Light Level					
		Starlight			Full Moon		
		Near	Mid	Far	Near	Mid	Far
SS	75°	61	64	89	45	51	47
	35°	44	61	56	33	39	51
	25°	47	64	65	29	49	44
CSWS	75°	45	41	97	58	49	60
	35°	51	60	70	38	44	53
	25°	37	51	91	35	45	60
NOD	75°	50	46	57	46	42	52
	35°	42	46	55	33	36	46
	25°	32	49	65	29	33	41

Search Area Size and Target Mode--Static vs Dynamic

In a previous experiment, it was found that probability of detection was about equal for moving and stationary targets under starlight and only slightly higher for moving targets under full-moon illumination. This finding was surprising, as it is commonly believed that target movement substantially increases the probability of detection. It was hypothesized that lack of substantial differences in the previous experiment was attributable to two factors: the restricted field of view of the devices and the size of the area to be searched. With the naked eye, movement can be seen with peripheral vision, causing the alert observer to orient in the direction of the perceived movement and thus increasing the probability of detecting a target. With viewing devices, however, the field of view is restricted, greatly reducing the use of peripheral vision and hence the value of movement as a cue. Additionally, in the previous experiment, device operators were continuously searching a large area (75° by 1500 meters) and were therefore more or less continuously moving their devices. Under these conditions, movement of a target would be less conspicuous than if the device was held relatively stationary, and a target moving across the device field of view would produce an obvious disruption of a static environment. It was therefore expected that in the present experiment, more moving than stationary targets would be detected when the narrow search sectors were used. The results are shown in Table 10. With the 75° search area, as in the previous experiment, somewhat more moving than standing targets were

detected under full-moon illumination--61% vs 55%, respectively, with the SS; 50% vs 45%, respectively, with the CSWS; 66% vs 66% (that is, no difference) with the NOD. Under starlight illumination, the differences actually favored the stationary targets--18% stationary vs 15% moving with the SS; 31% vs 21% with the CSWS; and 36% vs 35% with the NOD. With the 25° search sector, however, as hypothesized, more moving than stationary targets were detected under both illumination conditions, the difference in favor of the moving targets averaging about 25% under starlight and about 15% under full-moon illumination.

<u>Operational Implications</u>. When targets are expected to be moving rather than stationary, a narrower search sector will result in a considerable increase in target detection, particularly under starlight illumination.

Table 10

PERCENT TARGET DETECTION BY TARGET MODE
(Static vs Dynamic)

Device	Search Sector	Ambient Light Level: Starlight Stat	Starlight Dyn	Full Moon Stat	Full Moon Dyn
SS	75°	18	15	55	61
	35°	24	26	68	70
	25°	29	37	59	68
CSWS	75°	31	21	45	50
	35°	30	38	66	68
	25°	33	46	63	69
NOD	75°	46	35	66	66
	35°	47	61	69	70
	25°	51	60	61	76

Search Sector Size and Search Efficiency

The percentage detections presented previously in this report were based on the total number of targets presented. However, not all targets were seeable under all illumination conditions by all devices, and hence could not be detected. The previously reported data are meaningful because ability to see targets with the different devices is a function of the intrinsic properties of the devices and, as such, is an important contributor to their search effectiveness. However, another type of comparison is also meaningful. If all targets are seeable--that is, if the differences in device capabilities for seeing targets are

partialed out--how effective is the operator in finding targets that he can see? Information of this type has implications for operational employment of the devices, for engineering, and for improvement of search effectiveness. Therefore a technique was developed to determine how many targets were actually visible to a given operator with a given device on a given night, whether or not he found all those targets during search. This measure was labeled the Seeability index. Using this index as a baseline, a new measure, the Search Efficiency score, was obtained. An efficiency score of 100% would mean that all the targets that could be seen with a device were being detected during search, and further improvement in target detection could only be made by improvement in the device itself. The degree to which efficiency is less than 100% indicates the amount of improvement which is possible by other techniques. The procedures for deriving the Seeability index and the Search Efficiency score are described below, and the effect of search area size on Search Efficiency is shown.

Seeability Index. A subsample of one-third of the targets used in the experiment was selected for this measure. From this subsample, targets which were not detected by an individual during search were shown a second time with instructions indicating the target location. The operator was then tested to determine whether or not he could see the target. The entire subsample of targets was presented at the end of the evening's testing so as not to compromise search test data. The Seeability Index (SI) is derived as follows:

$$SI = 100 \left[\frac{\sum_{i=1}^{N} F_i + \sum_{i=1}^{N} S_i - \sum_{i=1}^{N} F_i S_i}{N} \right]$$

where F = targets found during search
S = targets seen without search
F S = targets both found during search and seen without search
N = number of targets

Division by N and multiplication by 100 simply converts the raw score into a percentage.

Table 11 presents the Seeability Index scores with each device under each illumination condition. Ability to see target increased with increasing illumination but to different degrees for the different devices, the increase being only slight with the NOD (from 90% to 96% for starlight and full moon, respectively) and much larger with the other devices (57% to 90% with the SS and 72% to 96% with the CSWS). Thus, differences among the devices were large under starlight but very small under full moon.

Table 11

PERCENT OF TARGETS WHICH COULD BE SEEN
(Seeability Index)

Device	Ambient Light Level	
	Starlight	Full Moon
SS	57	90
CSWS	72	96
NOD	90	96

Efficiency Score. Having determined the percentage of targets which were within the device capabilities, a new detection score was computed based on the number of targets which were seeable. This new measure, labeled the Search Efficiency Score, was obtained by dividing the original search detection score by the appropriate SI score. Thus, the Efficiency Score expresses the percentage of targets found during search as a function of percentage of targets that could be seen. An Efficiency Score of 100% would, therefore, mean that all the targets that could be seen with a device were being detected during search, and improvement in target detection could only be made by improvement of the device itself. To the extent that search efficiency is less than 100%, performance can presumably be improved by a number of techniques, including reduction in size of the search area, increasing the number of operators with devices, optimal search deployment of the operators, and changes in the search techniques and procedures used by an operator. The effects of reduction in search sector size on search efficiency are shown in Table 12.

Efficiency varied between 30% and 77%, depending upon device and condition, indicating that substantial improvement in target acquisition is possible without modification of the devices. Under starlight, reduction in size of search sector substantially improved efficiency, especially with the smaller devices. For example, 30% and 58% of the targets which could be seen with the SS were detected on the 75° and 25° search sectors, respectively--an improvement of 93%. With the NOD, the comparable values were 44% and 62%--an improvement of 41%. Under full moon, efficiency was much higher than under starlight and was virtually identical for all devices and for all search sector sizes with one exception--the CSWS on the 75° search sector. As was previously suggested, under these conditions the smaller field of view of the CSWS apparently makes it more difficult for an operator to rapidly search a large area but does not, of course, impair his ability to see a target--hence the lower efficiency.

Table 12

EFFICIENCY SCORE: PERCENT OF TARGETS FOUND DURING SEARCH AS A FUNCTION OF PERCENT OF TARGETS "SEEABLE"

	Ambient Light Level					
	Starlight Search Sector			Full Moon Search Sector		
Device	75°	35°	25°	75°	35°	25°
SS	30	44	58	64	77	71
CSWS	36	47	56	49	70	69
NOD	44	60	62	69	72	72

Operational Implications. Reducing the size of the search sector will improve search efficiency for all devices under low illumination and with the CSWS under high illumination. However, a substantial number of targets that are within device capabilities are not detected when a single operator is used, and use of multiple operators with devices should be considered, particularly under low illumination.

Implications for Basis of Issue

One means of increasing the probability of the timely and comprehensive detection of targets is by increasing the Basis of Issue (BOI). However, such an increase must be considered and evaluated in terms of the costs involved in manpower, devices, maintenance, etc. An earlier BESRL report[8] showed the relative gain obtained by increasing the number of devices for a relatively large search area. The purpose of the present analysis was to determine how BOI is related to search area sector, i.e., how much effectiveness is increased with increased BOI when the size of the search area is decreased. The approach to this problem was to statistically combine target detections by two or three operators who were simultaneously and independently searching a sector. A target was considered detected if one (or more) of the players, working independently, acquired the target. If more than one player found the target it was counted as only one acquired target.

Percent Detection. The percent of targets detected by one, two, and three operators under the various conditions is shown in Table 13. The percent detections increased with the number of operators, but the relative improvement in going from one to two operators was greater than that

[8] See footnote 1, page 9.

in going from two to three operators. This result was found for all search sector sizes, for all devices, and for both illumination conditions. Under full moon, although more targets were detected when a third operator was used, a cost-effectiveness tradeoff might not justify use of a third man, except in critical cases, because of the high percentage of targets detected by two operators.

Table 13

PERCENT OF TARGETS DETECTED WITH ONE, TWO, AND THREE DEVICE OPERATORS

		Ambient Light Level					
		Starlight Number of Operators			Full Moon Number of Operators		
Device	Search Sector	One	Two	Three	One	Two	Three
SS	75°	17	29	38	58	77	85
	35°	25	39	48	69	78	91
	25°	33	47	56	64	86	86
CSWS	75°	26	38	50	47	69	81
	35°	34	53	58	67	86	92
	25°	40	52	69	66	82	87
NOD	75°	40	59	68	66	86	89
	35°	54	74	81	69	87	94
	25°	56	72	80	69	84	92

The increase in target detection resulting from increased BOI was substantial on both large and small sectors, but improvement was greater on the 75° sector than on the two smaller areas, particularly under starlight. With the SS under starlight, for example, 17% of the targets were detected by one man on the 75° sector and 29% by two men--an improvement of 71%; on the 25° sector, however, 33% were detected by one man and 47% by two men--an improvement of 42%. Under full moon, the effects of search sector size were less than under starlight, but use of a second operator did result in a considerable improvement. With the SS, for example, 58% and 77% of the targets were detected by one and two operators, respectively, on the 75° sector; on the 25° sector, the comparable values were 64% and 86%--for both sectors, the improvement was about 33%.

Target Detection Time. The effects of increased BOI on time to detect targets was determined in the following manner. A target was considered detected if at least one player in the combination acquired the target. On occasion, a target was detected by more than one player

in a combination--that is, by both players in a pair or even all three players when combinations of three were used. On these occasions, the time of first detection was used.

The average target detection time for one, two, and three players, under the various conditions, is shown in Table 14. In general, there was moderate improvement in target detection time when the search sector size was decreased, regardless of the number of operators used. For example, with the SS under starlight conditions, target detection time for one operator was 62 seconds on the 75° sector and 52 seconds on the 25° sector; for three operators the comparable times were 57 seconds and 49 seconds. For all search sectors, increasing the number of operators generally resulted in a slight improvement in target detection time under starlight illumination (for the SS on the 75° sector, 62 and 57 seconds were required by one and three operators, respectively) and a much larger improvement under full moon (47 and 31 seconds being required by one and three operators, respectively, for the SS on the 75° sector).

Table 14

AVERAGE TARGET DETECTION TIME WITH ONE, TWO, AND THREE OPERATORS
(In Seconds)

		Ambient Light Level					
		Starlight			Full Moon		
	Search	Number of Operators			Number of Operators		
Device	Sector	One	Two	Three	One	Two	Three
SS	75°	62	60	57	47	39	31
	35°	50	47	45	38	28	23
	25°	52	50	49	37	32	28
CSWS	75°	46	42	39	55	48	42
	35°	54	51	50	43	33	27
	25°	43	40	36	42	34	30
NOD	75°	50	41	34	46	37	31
	35°	46	39	35	36	29	23
	25°	42	35	32	32	27	25

To summarize, under starlight, increased BOI resulted in a considerable increase in detections on all size search sectors but with greatest improvement on the 75° sector; the time required for target detection was only slightly reduced by increasing the BOI, and the reduction was about equal on all search sectors. For all search sectors, the greatest improvement in percent detection occurred when the number of operators was increased from one to two, but the increase in detections

was also substantial when the number of operators was increased from two to three. Under moonlight, search sector size was generally of relatively little importance and increased BOI produced relatively less improvement in percent detection than under starlight; detection time was reduced considerably by increased BOI. As performance under full moon was extremely high using two operators, the addition of a third operator did not greatly improve performancce, even when the search area was large.

Operational Implications. Use of two devices of the same kind, particularly under low illumination conditions, will result in improved capabilities, both in percent detections and detection time, and on both larger and smaller search sectors. This improvement is much more pronounced for the larger size search sector. Therefore, if tactically feasible, two men each using a device should cover the same search sector, particularly when the area to be covered is large and low illumination conditions prevail.

Implications for Search Deployment

The preceding analyses have shown the degree to which target acquisition is improved by reduction in the size of the search sector and by increase in number of operators searching a given size search sector. However, when the tactical situation dictates that a wide area must be covered and several men are available, how can they be most effectively used? Specifically, should the total area be divided into essentially non-overlapping sub-sectors with one man assigned to search each sub-sector; or should the local commander, to the extent the tactical and terrain situation permits, maximize overlap and have all the available men simultaneously search the entire area? The data were analyzed to determine the optimum techniques for the use of two and three men, assuming that the total area to be covered was 75° wide. When two men are used, each can be given a non-overlapping search sector of approximately 37° or both can search the entire 75° area. When three men are used, each can be given a non-overlapping search sector of 25° or, again, all can search the entire 75° area.

Percent Detection. The effect of overlapping versus non-overlapping search sectors on percent detection is shown in Table 15. Percent target detection was always higher with overlapping search sectors. Under starlight, performance with overlapping search sectors was about 10% better than for non-overlapping sectors (across all devices) when two men are used, and about 20% better when three men are used. Under full moon, performance with overlapping search sectors was about 15% and 30% better than with non-overlap for two and three men, respectively. Thus, the advantage of using overlapping search sectors was greatest when more men were involved and under high illumination conditions.

Table 15

PERCENT TARGET DETECTION WITH OVERLAPPING AND NON-OVERLAPPING SEARCH OF A 75° AREA

	Ambient Light Level							
	Starlight Number of Operators				Full Moon Number of Operators			
	Two Men		Three Men		Two Men		Three Men	
Device	Non-Overlap	Overlap	Non-Overlap	Overlap	Non-Overlap	Overlap	Non-Overlap	Overlap
SS	25	29	33	38	69	77	64	85
CSWS	34	38	40	50	67	69	66	81
NOD	54	59	56	68	69	86	69	89

Target Detection Time. The effects of overlap and non-overlap on target detection time are shown in Table 16. Under full moon, there seems to be little difference between the two methods; under starlight, overlap reduced target detection time for some devices and not for others. In general, therefore, neither deployment technique showed an advantage in terms of detection time.

Table 16

TARGET DETECTION TIME WITH OVERLAPPING AND NON-OVERLAPPING SEARCH OF A 75° AREA (In Seconds)

	Ambient Light Level							
	Starlight Number of Operators				Full Moon Number of Operators			
	Two Men		Three Men		Two Men		Three Men	
Device	Non-Overlap	Overlap	Non-Overlap	Overlap	Non-Overlap	Overlap	Non-Overlap	Overlap
SS	50	60	52	57	38	39	37	31
CSWS	54	42	43	39	43	48	42	42
NOD	46	41	42	34	36	37	32	31

Operational Implications. Results of this analysis suggest that a search area should not be fractionated into smaller sub-sectors. To maximize the number of targets detected, when tactically feasible all men should search the entire area.

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13. ABSTRACT

The NIGHT OPERATIONS Program within the Behavior and Systems Research Laboratory (BESRL) is concerned with optimizing human performance in relation to night vision devices and related sensors. Specific aspects deal with determining performance effectiveness of sensor systems, factors which affect performance, and means of improving effectiveness. ~~To further this research,~~ a BESRL field unit at Fort Ord, California, with the support of the Combat Developments Command Experimentation Command (CDCEC), is currently conducting experimentation with passive night vision devices. The present study, conducted with the assistance of personnel of the Manned Systems Sciences, Inc., describes research involving the use of such devices in assessing the effectiveness of soldier performance during night operations. The primary objective of the experiment was to investigate the effects of search area size on performance--as it interacts with a number of environmental, target, and human factors--and to determine the implications of findings for operational use, basis of issue, and search deployment, as well as for improvement of soldiers' effectiveness in using these devices. 135 operators were tested (9 each night) in target detection under three ambient light levels (starlight, half moon, and full moon). The players were required to search for targets (differing in type, contrast, and mode of presentation) over search areas defined by scan angles of 75°, 35°, and 25°. Subjects used the Starlight Scope (SS), the Crew Served Weapon Night Vision Sight (CSWS), and the Night Observation Device, Medium Range (NOD). Detection responses and search behavior were recorded on magnetic tape for data analysis. Major findings indicated: 1) reduction in search area size greatly improved operator efficiency, particularly under low light (starlight) conditions; 2) target

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Device deployment						
*Ambient light levels						
*Detection responses						
*Search behavior						
Instrumentation						
Methodology -- research						
Target modes						
SS						
CSWS						
NOD						
Operator performance measurement						
*Target-terrain factors						
*Target-distance factors						
Military psychology						
Training						
Field experimentation						
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13. ABSTRACT continued

acquisition was affected by search area size in relation to target mode (stationary vs moving) and to distance; 3) improvement in operator effectiveness was greatest for wide search areas when the number of devices was increased; 4) when the search area was narrowed, there was a significantly greater improvement in detection of distant targets than of close targets; 5) when more than one operator was used, more targets were detected when the search involved overlapping sectors than when the area was divided into sub-sectors. Results suggest how target acquisition can be improved by reduction in search area size and by use of multiple properly deployed devices.